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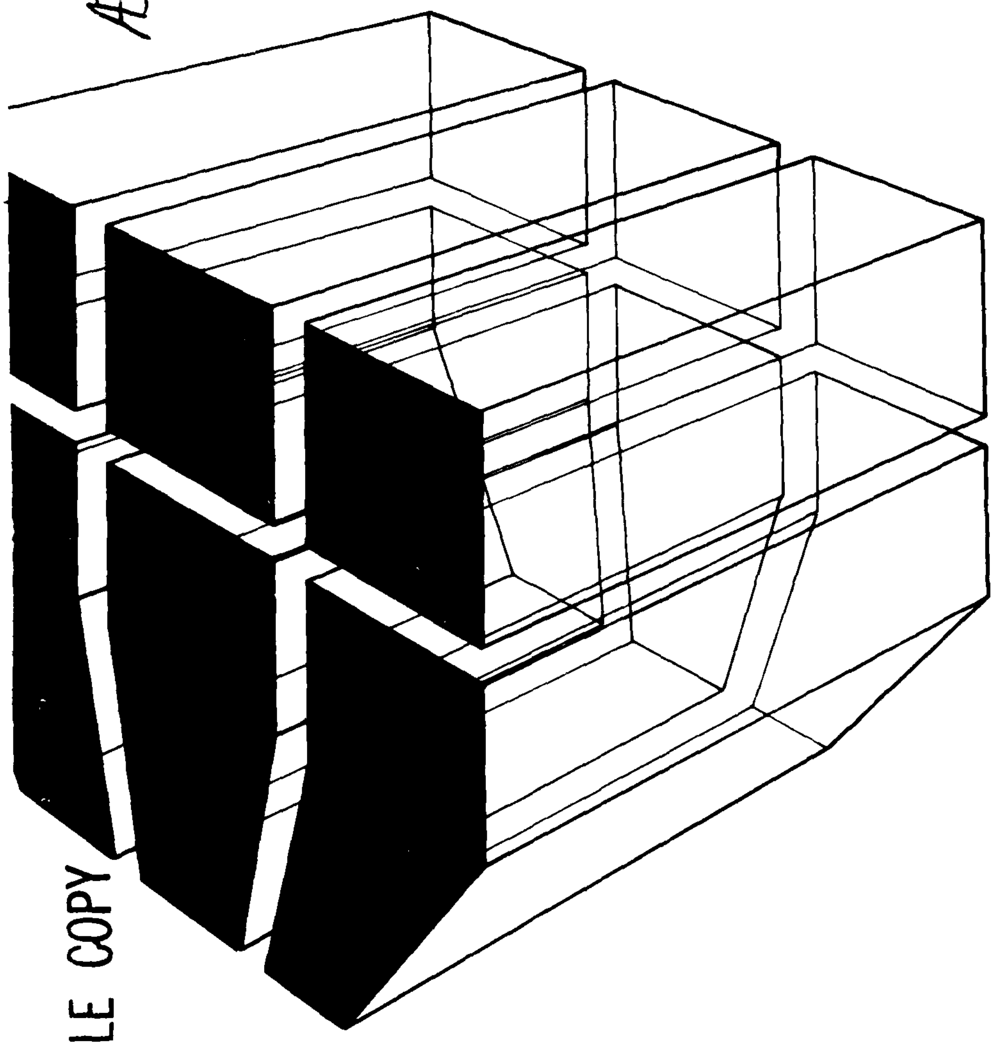
CAEADS—COMPUTER-AIDED ENGINEERING AND ARCHITECTURAL DESIGN SYSTEM



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CAEADS, an automated integrated system to support the design of military facilities, is being developed by the U.S. Army Construction Engineering Research Laboratory through the Corps of Engineers' RDTE Program. When completed, the entire CAEADS system will support the design process starting at the initiation of a requirement for a facility, and continue through to the design (preliminary and final) and the production

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of working drawings, specifications and cost estimates. Presently, Concept CAEADS integrates tools for use in preliminary design. Concept CAEADS has been extensively tested by architects and engineers on the design of 200 projects in the FY84 Military Construction Army Program. During this test, Concept CAEADS was used to organize project requirements, lay out facility floor plans, evaluate designs for functionality and energy usage, do preliminary cost estimates, and produce concept-level drawings. By using Concept CAEADS' tools and exploiting repetition in the design workload, costs for concept design were reduced substantially. These savings are attributed to adaptation of standard designs in an integrated environment, where design changes are made simply and quickly.

This paper presents the findings of the recent Concept CAEADS test and describes future CAEADS development -- Predesign and Final Design CAEADS.

FOREWORD

This paper was presented at the 1982 Army Science Conference, held at the U.S. Military Academy, West Point, New York, 15-18 June 1982. The CAEADS work was performed for the Directorate of Military Programs, Office of the Chief of Engineers, under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Facility Planning and Design"; Work Unit 020, "Computer-Aided Engineering and Architectural Design System." Mr. Vincent Gottschalk, DAEN-MPE, was the OCE Technical Monitor.

The work was performed by the CAEADS Team, Facilities Systems (FS) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. Ed Lotz is Chief of CERL-FS, and Janet Spoonamore is Team Leader for the CAEADS team.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CAEADS — COMPUTER-AIDED ENGINEERING AND ARCHITECTURAL DESIGN SYSTEM (U)

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The U.S. Army Corps of Engineers Construction Engineering Research Laboratory is developing the Computer-Aided Engineering and Architectural Design System (CAEADS) to support the design of military facilities. CAEADS' support will start with initial requirements for a facility, and continue through concept and final design and the production of construction drawings, specifications and cost estimates. The CAEADS system will be integrated based on a central source of design information used by all the disciplines in the design process: users, project planners, architects, engineers, specification writers, and cost estimators and drafters.

In October of 1981, the integration of the concept design tools of the CAEADS system was completed and a test initiated involving 200 projects in the Military Construction Army (MCA) FY84 program. This integrated system, called Concept CAEADS, is used to support preliminary design, from project requirements through to the 25 percent design level. Concept CAEADS provides tools for project information retrieval, facility layout, functional evaluation, energy evaluation, cost estimating and production of drawings. During the period 1 October 81 to 1 February 82, one architectural engineering firm tested and used Concept CAEADS to design to 25 percent these 200 MCA projects. The findings of the test suggest that substantial design cost reductions will be realized. The purpose of this paper is to report on the Concept CAEADS test objectives and findings and describe the development of a further integration of design tools — Predesign and Final Design CAEADS.

Background

The Corps of Engineers is the largest construction industry in the world. Each year, the Corps' MCA program includes several hundred projects consisting of some 50 facility types in various stages of planning, design or construction. For several years, total MCA construction has

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grown both in volume and technical complexity. Keeping construction costs low given increasing demands for energy and concerns for safety, accessibility, and efficiency in an environment of rising construction labor and material costs is a great challenge. This challenge means the Corps must design the best possible facilities, reuse these "best" designs, and manage construction programs to optimize on repetition. Further quality can be gained and time saved by using automated tools to support design layout, analysis and drawing production on repetitive, "similar" projects. The CAEADS system is being developed to meet this objective; i.e., to reduce design costs and increase the quality of design.

Computer-Aided Design Technology

Computer-aided design (CAD) tools for engineering and construction have been adapted mainly from manufacturing and business applications; software for accounting, specification production and drafting are presently available. These individual tools now are being linked using a geometric description of the design, i.e., a central source of data. Computer graphics and geometry are used like balsa-wood models, but can do much more -- functional analysis, quantity take-offs, statistical analysis, and heating and cooling analysis, etc. For example, using the geometric operations, interferences between the layout of structural elements and heating, ventilating, and air conditioning (HVAC) ducts can be detected. According to Engineering News-Record (December 1981), CAD may bring the most profound changes in standard procedures the design profession has ever seen (1).

CAEADS focuses on assembling hardware and software tools affordable by and compatible with the architect/engineer (A/E) organizations that will be using the system on Corps projects (2).

The benefits an integrated system such as CAEADS will offer the Corps are far-reaching. The MCA design process can be shortened and strengthened using CAEADS. CAEADS can increase productivity, and help the Corps exploit the opportunity of repetition of similar designs. (Repetition is especially amenable to automation.) CAEADS allows more analyses to be performed to detect design errors such as interferences in construction, poor layout, etc. CAEADS also gives the Corps an efficient way to make continual evaluations to trade off expected construction costs and operating energy costs. CAEADS will produce benefits and savings in the design, construction and operation and maintenance of facilities.

Concept CAEADS Description

CAEADS has only recently become available as an integrated system. Over the past several years, CERL and other Corps organizations have developed specific, stand-alone application tools under the CAEADS umbrella. The systems include the Design Information System (DIS), developed by the Office of the Chief of Engineers; the Automated Budget Estimating System (ABES) and the Computer-Aided Cost Estimating System (CACES), developed by the U.S. Army Engineer Division, Middle East (Rear); and the CERL-developed DD 1391 Processor, the Systematic Evaluation of Architectural Criteria (SEARCH), the Computer-Aided Facility Layout System (SKETCH), the Building Loads Analysis and Thermodynamics (BLAST) System, and the Computer-Aided Specification Preparation System (EDITSPEC).

Concept CAEADS integrates automated tools for use at the early stages of design, primarily the functional layout and analysis phases. Figure 1, "CAEADS Concept Design," depicts these tools. The system helps designers organize project information, lay out design alternatives, analyze for compliance to functional requirements, evaluate energy consumption and costs, estimate direct project costs and produce scaled drawings. Concept CAEADS provides a 3-dimensional data base from which final design can be initiated.

In the concept design phase, the designer will generate one or more conceptual design solutions. Each alternative is evaluated and reviewed to assure it complies with the facility users' needs and other design criteria.

The Concept CAEADS design process includes the following steps:

1. The DIS module is used to review the MCA project design information in a given fiscal year and identify projects that can use "as-designed" standards. Project information is maintained at a summary level in the DD 1391 Processor data bases.

2. The SKETCH module is used to develop custom layouts or to modify standards. The system provides layout tools for rooms, walls, doors, windows, ceilings, floors, furniture and equipment, thermal zones and associated construction materials.

3. The SEARCH evaluation modules are used to check alternatives to assure they comply with a project's functional requirements. These include area, walking distance, acoustic separation, visual control and handicap accessibility codes.

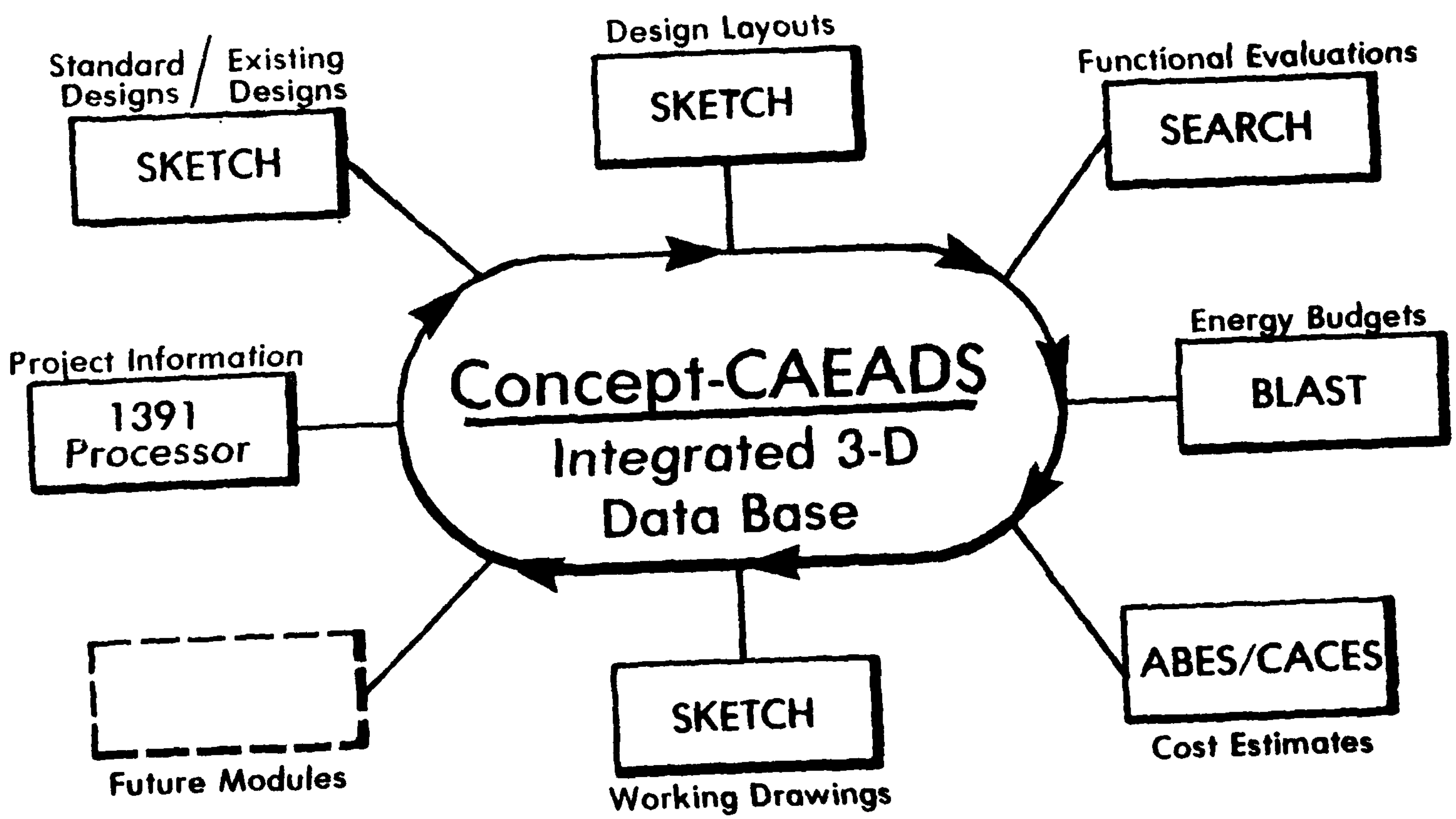

Figure 1. CAEADS Concept Design

4. The BLAST module analyzes alternatives for energy consumption and costs (3). BLAST predicts consumption based on simulated geographic weather and building operations.

5. The ABES/CACES modules prepare preliminary cost estimates for each alternative. A data base library of construction and unit costs is maintained in the system.

Designers access Concept CAEADS using low-cost graphics workstation terminals. Layouts are entered using the terminal thumbwell movements; displays are shown on the terminal screen. Hardcopy plots of final layouts can be produced. The functional evaluation, energy usage and cost estimate reports also are produced by the system at this workstation.

Concept CAEADS currently operates on timesharing services at the University of Michigan, Michigan State University, and the Mid-East Rear Division.

Concept CAEADS Test Objectives

The test of the Concept CAEADS system had three objectives:

1. Determine the usability of a system like CAEADS.

2. Determine the costs and benefits of applying CAEADS to a design workload.

3. Determine the design workload distribution which would ensure the highest payoff using CAEADS.

Usability

A system like CAEADS may or may not be accepted and properly used by practitioners, although it closely supports normal design practice. Human factor issues are very important. The use of automation in architectural/engineering practice historically has been very low compared to other professions. But with the initiation of computer-aided drafting in the A/E community, it seems likely that a CAD system will be accepted and used. Only the essential differences between automated drafting and automated design tools need to be explored. Table 1, "Summary of Concept CAEADS Versus Automated Drafting," shows the differences between drafting tools and design tools. The Concept CAEADS test helped determine whether these design tools could be incorporated into practice, in much the same way as drafting tools have been.

Table 1

Summary of Concept CAEADS Versus Automated Drafting

Automated Drafting (Typical turn-key system)

- Drawing tools
  - Definition of levels/pages
  - Definition of repeating group of elements
  - Layout of elements
    - Annotation
    - Points
    - Lines
    - Polygons
    - Polyhedron
    - Group of elements
  - Modification of above (changes or deletions)
  - Line-weighting, cross-hatching, fill, font selection, paragraphing, formatting.
  - Dimensioning notation (semi-automatic)
  - Accuracy controls (snapping to grids, points)
- Plotting tools
  - Selection of scale, region to be plotted.
- Association of elements to nongraphic data

Concept CAEADS

- Design tools
  - Definition of project criteria
    - Room areas/proximities/visual control
    - Handicap criteria
    - Location
  - Layout of alternative plan elements
    - Floors, ceilings, roofs, doors, windows, equipment/furniture or groups of these
    - Selection of materials for above
    - Automatic generation of room polygons
    - Definition of room names and HVAC zones (plants, air handling)
    - Stretching/shrinking capability
    - Accuracy controls (snapping to grids, points, angles)
- Analysis tools
  - Calculation of layout against project criteria
  - Calculation of quantities and direct costs
  - Calculation of heating/cooling BTUs
- Plotting tools
  - Automatic generation of scaled drawings
- Translation of elements into graphic data for further lineweighting, dimensioning, annotation, fill and font selection.

The test showed that Concept CAEADS could be applied directly to design practice. Training on the system (i.e., learning the system functions and applying them to the design efforts) went well throughout the course of the test. Only simple problems occurred during the test, including computer "downtime," causing work stoppage; minor system errors; and user difficulties in not understanding how the system operated. During the first several weeks of the test, the A/E staff quickly adapted to the new functions offered by Concept CAEADS.

Midway through the test, the A/E staff was asked to fill out a questionnaire about the system's utility and ease of use. The questionnaire also asked the A/Es to compare Concept CAEADS to manual and automated drafting approaches, and to suggest improvements. The users who actually operated the system included three architects and one mechanical engineer. These persons used the SKETCH system to do floor plan layouts and to specify HVAC zones and building materials. They also ran off the SEARCH drawings, BLAST energy profiles and ABES/CACES cost estimates.

The questionnaire results indicated the staff felt the system was useful for adapting past project or definitive layouts to meet established criteria. They also felt the system's strong evaluation features were useful. Their negative reactions focused on several of the user protocol procedures, which they felt slowed their performance. Based on their recommendations, many of these procedures already have been enhanced and are now much easier to perform.

Costs/Benefits

The use of Concept CAEADS on 200 MCA project designs produced considerable savings over current practice. It should be noted that savings were realized not only from use of the system, but also from the consolidated design workload on which the system was used. The costs for the 200 projects included design personnel costs, computer timesharing services costs, equipment rental costs and software maintenance/training personnel costs. These costs are shown in Table 2, "Concept CAEADS Test Costs." Costs using current methods of design practice were derived from typical project design costs incurred in the past. An average cost for 25 percent project design (on similar design workloads) was approximately $16,000 using current manual methods. The number of completed projects in the test workload was 113 out of the original 205 started. Ninety-two projects were cancelled during the progress of the work. On the average, these 92 projects were completed to about 10 percent. The costs to perform the design using current practice are shown in Table 3, "Current Practice Costs."

Table 2

Concept CAEADS Test Costs

Costs	
Design personnel	$200,000
Automated data processing *timesharing*	100,000
Equipment rental	16,000
Software maintenance/training	40,000
	$356,000

Table 3

Current Practice Costs

Projects	Cost/Project	Total
113	$16,000	$1,808,000
92	6,400	588,800
	TOTAL	$2,396,800

Table 3 shows that more than $2 million in cost savings were realized using Concept CAEADS.

Design Workload Distribution

As mentioned earlier, the users of the Concept CAEADS system felt the system was amenable to adapting designs based on definitive or past project layouts, and that design workload distribution was an important ingredient in realizing high-payoffs from automation. Table 4, "Project Distribution," shows the range and scope of facilities designed. This workload included new construction of building projects.

Table 4

Project Distribution

	Category Code	Number of Projects	Approximate Square Feet
141	Field operations	5	9,000
		2	13,000
		2	18,500
		1	4,000
171	Headquarters	1	4,000
		6	12,000
		2	17,000
		1	25,000
		1	28,000
		1	35,000
211	Hangars	6	Ranges (25,000 - 63,000) Average (41,500)
214	Vehicle maintenance	9	4,000
		2	14,000
		2	19,000
		1	26,000
		1	29,000
		2	33,000
		1	49,000
		2	225,000
219	Maintenance -- FE	1	12,000
		1	12,000
		1	28,000
		1	34,000
610	Administration	2	3,500
		1	35,000
		1	85,000
722	Dining	3	8,000
		3	12,000
		1	16,000
		1	48,000

Table 4 (Cont'd)

Category Code		Number of Projects	Approximate Square Feet
723	Company administration	4	5,000
		1	14,000
		1	19,000
		2	24,000
		1	29,000
		1	34,000
		2	43,000
		1	71,000
		1	78,000
724	Officers housing	1	52,000
730	Fire stations	2	5,000
		2	6,000
740	Morale support	19	Ranges (3,000-62,000)
	• Child care		Average (30,000)
	• Eduction/library		
	• Physical fitness centers		
	• Recreation centers		

As expected, there was considerable variation in layout time required to modify drawings versus original custom design layout. The online usage data collected during the test revealed an average of 12 hours per layout (minimum 0, maximum 24 hours) with a standard deviation of 15. Having access to a central library of design layouts and tools to modify these floor plans for specific project requirements and location gave designers the opportunity to "reuse" designs. This approach resulted in the lowest possible design costs at no sacrifice to quality.

Further Developments

This extensive test answered several questions. CAEADS easily can be incorporated into design practice -- it is usable. It is cost effective and the repetitive workload of the MCA program is especially amenable to high-cost avoidance.

Two main questions arose during the test which must be answered. First, project design information is sometimes lacking at the start of the design process. How can this project requirement information best be collected and organized for design initiation? Much of this data is generated by the Army installation user, and ultimately is documented in the Project Development Brochure (PDB). Proposed construction projects must

be approved and contained in the Installation Master Plans (including the approved site). A new module of CAEADS -- Predesign CAEADS -- will be developed to integrate the tools to support the development of project requirements (functional and technical requirements), the analysis of supporting utility requirements compared to capacity and environmental and economic impact analysis. Predesign CAEADS will be used primarily by Corps district offices supporting installations preparing MCA project information.

A second question posed during the test regards the transition of the concept design into final design (usually performed under A/E services). Given project designs completed to concept level, a means must be provided to transfer these designs to the many A/E firms which ultimately will provide working drawings, specifications and detailed design analysis. The system which will provide this transition is called Final Design CAEADS. This system will integrate several of the stand-alone systems previously mentioned (BLAST, CACES, EDITSPEC) and a sophisticated 3-dimensional modeling data base for representing the design. The 3-dimensional data base provides a central source of data from which specifications can be prepared, quantities calculated for detailed cost estimates and analysis performed (structural, electrical and mechanical). The system ARCH:MODEL, developed by the University of Michigan Architectural Research Laboratory, will provide the data base handling and geometric modeling tools needed for fully representing and retrieving the elements of design, i.e., doors, windows, ceiling, roof, foundations, structure, mechanical and mechanical/electrical conduit (4). ARCH:MODEL's geometric operations on 3-dimensional polyhedra allow for checking interferences in building system layout. Presently, an interface has been developed to transfer concept-level floor plans into a 3-dimensional model of the facility design. Figures 2 through 7 depict the development of a design using ARCH:MODEL.

Conclusions

The recent test of Concept CAEADS has provided a unique opportunity to evaluate the impacts of CAD on a wide range of project design workloads. The findings of the test show the usability of CAD in design practice and the benefits of CAD applied on a consolidated concept design workload. Development of the Predesign and Final Design modules of CAEADS will be performed over the next 5 years.

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(3) "The Building Loads Analysis System Thermodynamics (BLAST) Program, Version 2.0: Users Manual, Volume I," U.S. Army Construction Engineering Research Laboratory, Champaign, IL, CERL-TR-E-153, June 1979.

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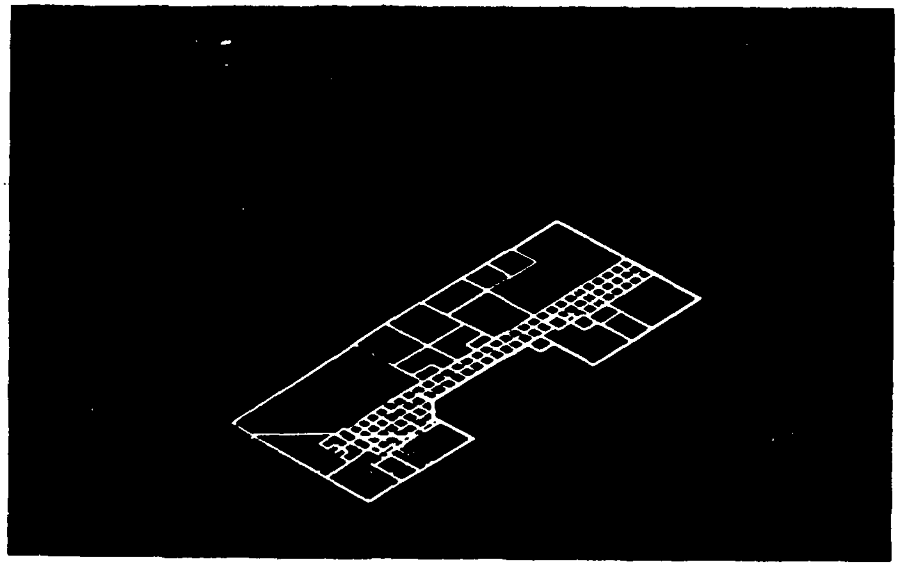

Figure 2. Transfer of layout to 3-dimensional model (includes ceramic floor tiles for passive solar design).

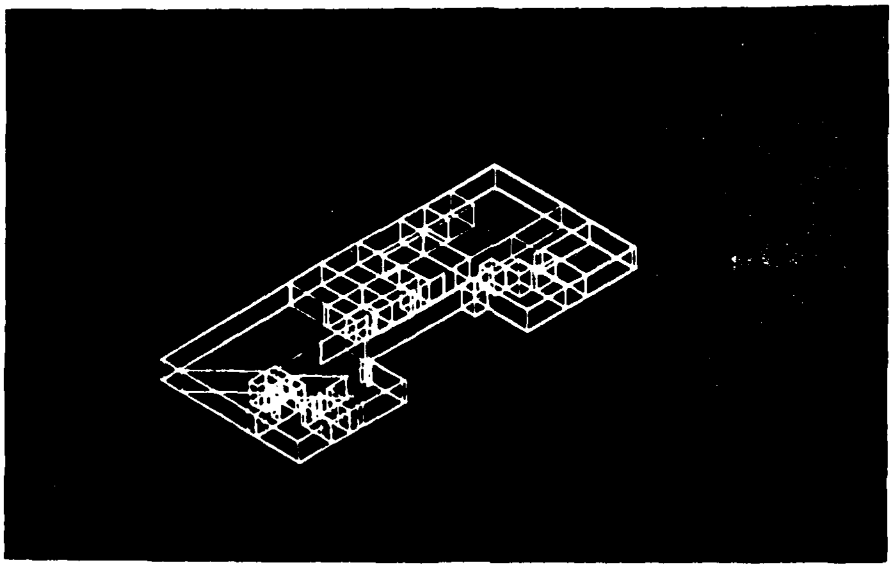

Figure 3. Extrusion of walls into 3-dimensional polyhedron.

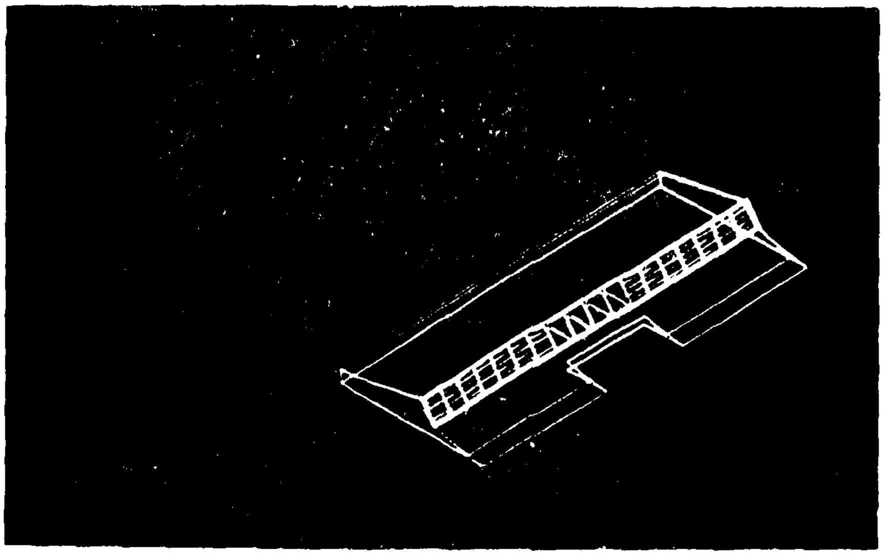

Figure 4. Roof section laid out in SKETCH and extruded. Louver windows and solar collection panels are built in 2-dimensions and placed on roof.

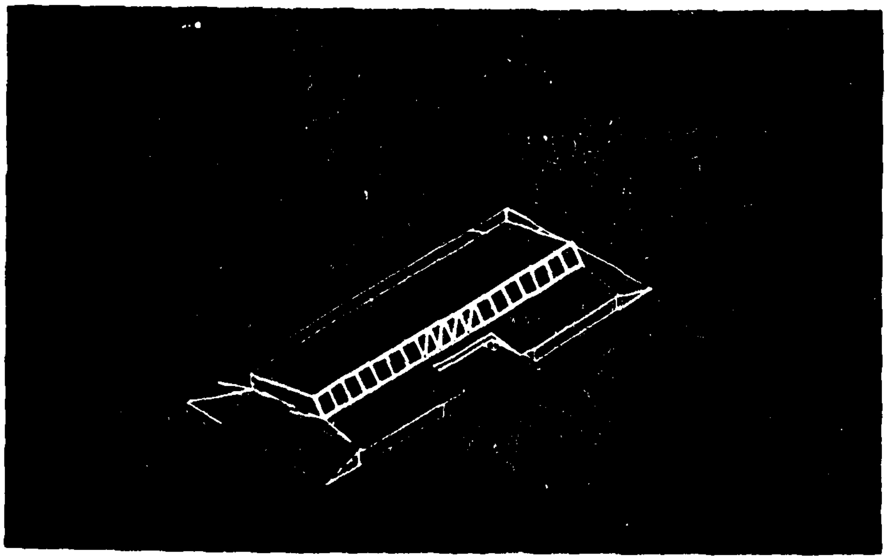

Figure 5. Roof is placed on building and berms are placed on north, west and east sides.

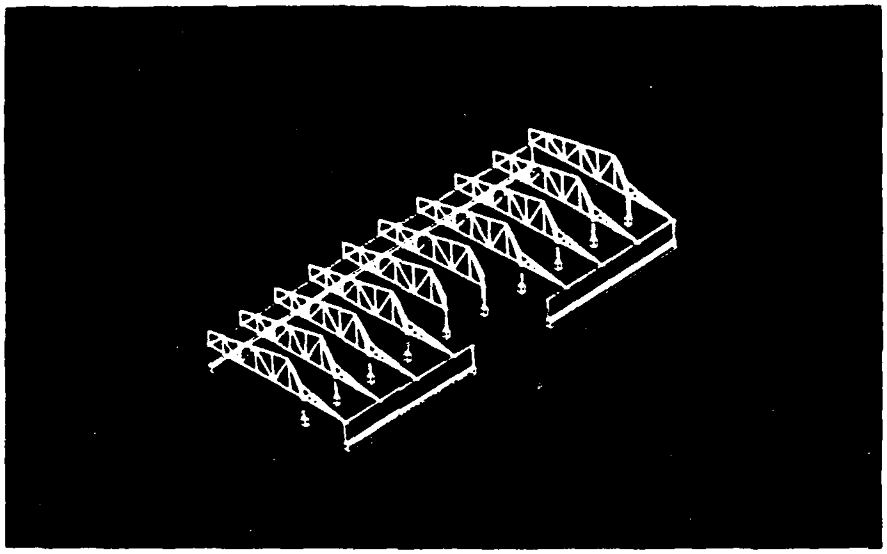

Figure 6. Footings, foundations, columns, and girders are sketched and extruded. Presently, sizing and layout are calculated outside CAEADS. Eventually, an automated interface will be provided.

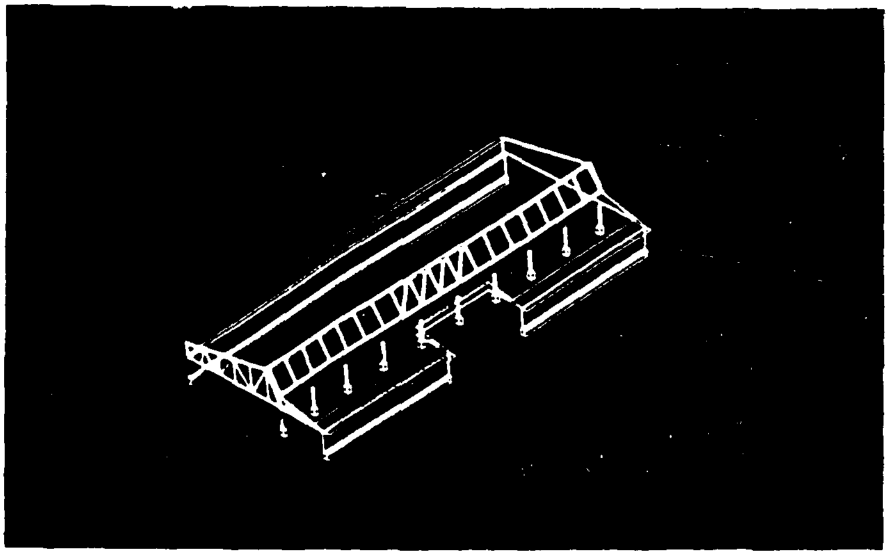

Figure 7. Conflicts in placement of components can be detected, e.g., the girder and roof.

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